DESIGNING AN IN-HOME SCALABLE ROBOTIC ARM EXOSKELETON FOR HAND REHABILITATION THERAPY

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Dedicated to my parents, Helene and Stuart Tuck.

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I would like to thank my mother and father, without whose guidance and support I would not be here.

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SUMMARY

Cerebral palsy and stroke are both debilitating neurological disorders that may permanently damage a person’s body movements and muscle coordination. Recent methods to help facilitate therapy in cerebral palsy patients and stroke survivors include the patient interacting with a robotic arm exoskeleton that is connected to a tablet gaming suite, which has shown to encourage the patient to complete his or her rehabilitation regiment. A major problem currently facing robotic arm exoskeleton rehabilitation therapy is that commercially available robotic arm exoskeletons are relatively bulky, heavy, expensive, and typically fit only one size, limiting the amount of patients who can benefit from this therapy. This paper describes a method to create an easily scalable robotic arm exoskeleton for use in hand rehabilitation therapy, through 3D printing. This paper then illustrates a study where the developed robotic arm exoskeleton was compared to a commercially available robotic arm exoskeleton in order to determine efficacy.

CHAPTER 1

INTRODUCTION

Cerebral palsy and stroke are both debilitating neurological disorders that may permanently damage a person's body movements and muscle coordination [1] [2]. Neurological disorders associated with cerebral palsy appear as early as infancy [1]. Victims of cerebral palsy and stroke are commonly treated through physical therapy. One of the most important factors to the overall health of a cerebral palsy patient or a stroke survivor (in this paper, both referred to as "patients" for simplicity) is their perceived quality of life. Patients undergoing physical therapy commonly exhibit pain and boredom with their rehabilitation regiment, which studies have shown may lengthen recovery time. Conversely, physical therapy that keeps the patient engaged is more likely to shorten patient recovery time [3].

In the field of robotic rehabilitation therapy, past research suggests that subjects interacting with a rehabilitation robot arm exoskeleton connected to a rehabilitation gaming system remain more engaged throughout their exercise routine and are more likely to complete a rehabilitation regiment consisting of physical therapy [4]. This research was conducted using a 2005-version Hand Mentor, a commercially available robotic arm exoskeleton [5].

For children, a robotic arm exoskeleton to facilitate rehabilitation is non-existent. Additionally, current commercially available robotic arm exoskeletons are relatively bulky, heavy, expensive, and typically fit one size. This study ultimately hopes to show the feasibility of building a robotic arm exoskeleton that is suited for a particular patient, relatively light, and relatively inexpensive.

Past research in the field of noninvasive motor skill therapy has led to the development that invasive methods (such as surgery) are not necessary to retain a motor skill for a long-term period. It has been shown that constraint-induced movement therapy, mental practice with motor imagery, and robotics may assist and aid a post-stroke survivor [6]. In addition, it has been shown that certain noninvasive methods create a memory "consolidation mechanism" which allows for significant memory retention [7]. In particular, the finding in [7] implies that noninvasive methods can be used to significantly improve memory retention.

Researchers have investigated potential noninvasive therapies to use with a robotic arm exoskeleton to facilitate therapy. Specifically, a study has been conducted to determine if a video gaming system can be attached to a therapy-related robotic arm exoskeleton to create a more useful therapy system. This system consists of a commercially available hand rehabilitation robotic arm exoskeleton, a computer tablet, and a computer game. This study shows that the robotic arm exoskeleton video gaming system engages the subject significantly more than the control, and that participants were more likely to complete their therapy routines with the robotic arm exoskeleton video gaming system [5].

In continuation of the research conducted in [5], research was then conducted on determining the efficacy of various therapies for stroke and cerebral palsy patients. In the current study, a robotic arm exoskeleton was combined with a tablet video game to rank the efficacy of several motor recovery therapies versus a control therapy. Accounting for hand injuries for varying degree, this research suggests that it is possible to encourage specific motions via video game control. Furthermore, this study's discovery suggests that a video game can be programmed to specifically encourage a particular therapeutic motion [8].

CHAPTER 2

METHODS AND MATERIALS

Robotic Arm Exoskeleton Fabrication

The robotic arm exoskeleton is being developed in SolidWorks, a computer-aided design (CAD) software package. SolidWorks offers flexibility in terms of scaling, and is useful when 3D printing. Figure 1 shows a SolidWorks model of the robotic arm exoskeleton, with three sizes.

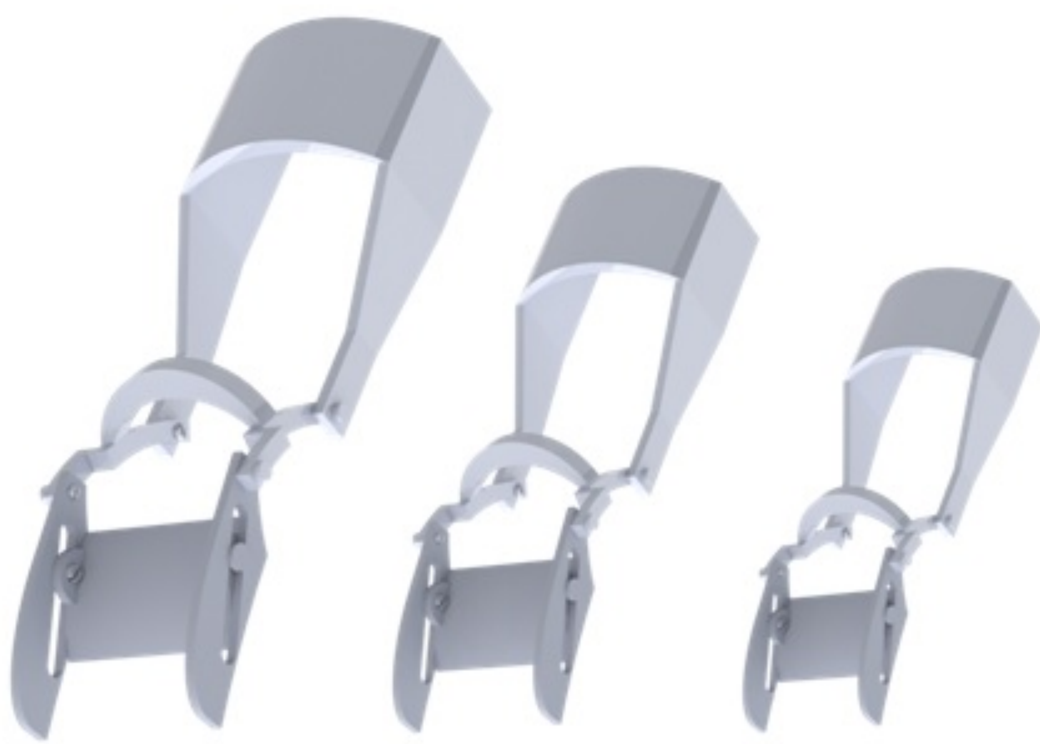

Figure 1. SolidWorks model of the robotic arm exoskeleton, in three different scaled sizes.

The main portions of the SolidWorks development of the robotic arm exoskeleton cover and support the arm, wrist, hand, and fingers. The arm portion of the exoskeleton covers the arm from the elbow to the wrist, and includes two holes that allow attachment with the wrist portion of the exoskeleton. The wrist portion of the exoskeleton allows for maximum movement of a patient's dorsiflexion (backward bending of the hand) and palmar flexion (forward bending of the hand). The hand portion of the exoskeleton includes two braces for both sides of a patient's hand, which includes an extended hole to allow for the adjustment of the finger bed. The finger bed is included to allow for finger and overall arm stabilization onto the robotic arm exoskeleton.

After development in SolidWorks, the robotic arm exoskeleton is printed using a 3D printer. Not only does a 3D printer allow for rapid prototyping, but the Acrylonitrile butadiene styrene (ABS) plastic used to print the parts of the robotic arm exoskeleton are relatively less dense and less expensive than materials used to fabricate current commercial models of the robotic arm exoskeleton.

Once the robotic arm exoskeleton has been printed using the ABS plastic, electronics are embedded onto it. A potentiometer is used to map the movements of the participant's wrist to a voltage. This voltage is read into an Arduino Uno, a popular low-cost, open-source microcontroller [9]. Figure 2 is a picture of the completed robotic arm exoskeleton, with an arm length of approximately 34cm and an arm/wrist width of approximately 10cm.

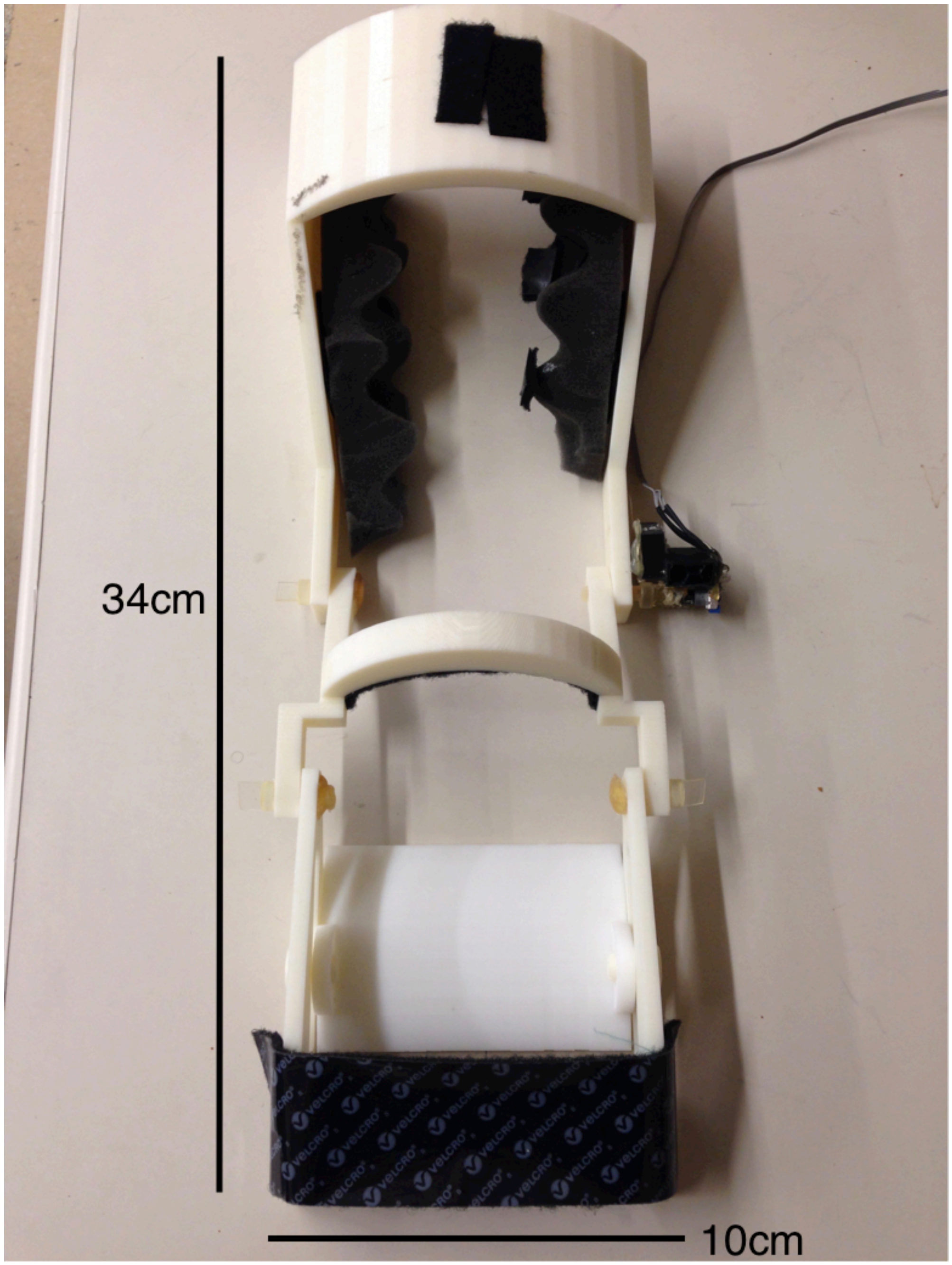

Figure 2. A picture of the completed robotic arm exoskeleton with arm length of approximately 34cm and arm/wrist width of approximately 10cm.

Validation of the Robotic Arm Exoskeleton

The developed robotic arm exoskeleton was experimented with in order to verify its efficacy versus a commercially available robotic arm exoskeleton, the 2005 Hand

Mentor, so that it may be used in the future as a viable alternative. In particular, these experiments were used to validate not just that the robotic arm exoskeleton works, but also that the entire robotic arm exoskeleton tablet gaming suite offers the ability to increase engagement in a patient's physical therapy regimen [10]. From these experiments, it is possible to logically deduce whether or not this fabricated robotic arm exoskeleton shows promise as a viable alternative.

In the first validation experiment, able-bodied participants were asked to participate in a series of wrist rehabilitation exercises, with and without the robotic arm exoskeleton tablet gaming suite, until the participants become bored. Institutional Review Board approval was given to conduct this study.

CHAPTER 3

RESULTS AND DISCUSSION

From the sample size of 14 participants, it is shown that the mean time spent exercising with the robotic arm exoskeleton is significantly greater than the mean time spent exercising without the robotic arm exoskeleton, which experimentally shows the viability of using a robotic arm exoskeleton to increase engagement in wrist rehabilitation exercises. Figure 3 shows the results gathered from the aforementioned experiment [10].

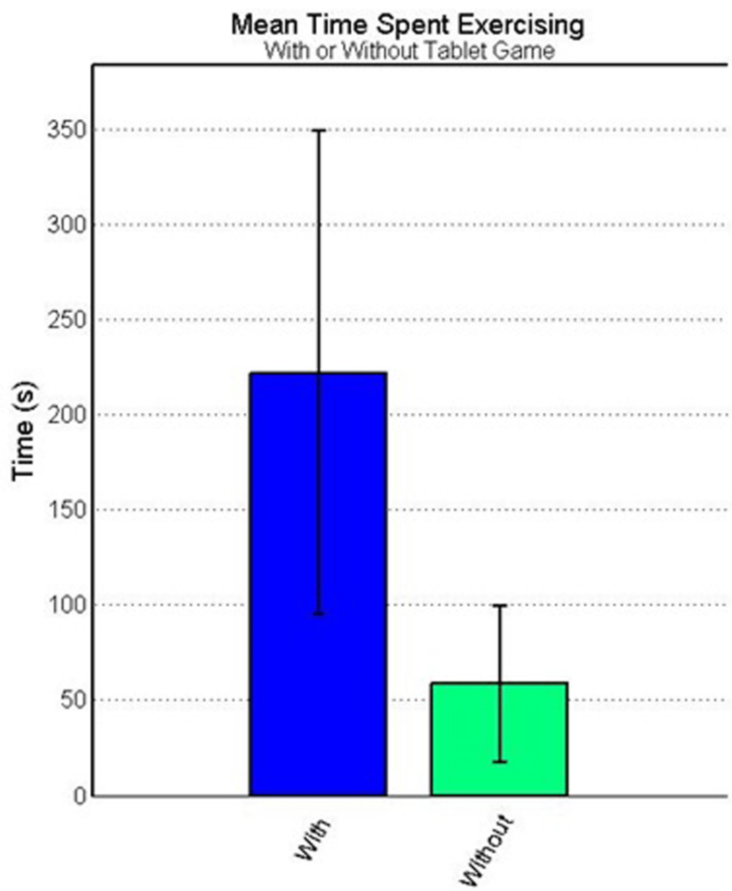

Figure 3. Graph illustrating mean time spent conducting wrist rehabilitation exercises before participant boredom, with and without the robotic arm exoskeleton gaming suite [10].

From the results, it can be seen that the participants significantly spend more time exercising their wrist while connected to the robotic arm exoskeleton gaming suite than without the gaming suite. The results of this experiment imply that 3D printing a robotic arm exoskeleton and embedding it with electronics may be a feasible alternative to commercially available robotic arm exoskeletons.

Factors

It is proposed that the main factor behind these results stems from the relative size and weight of the 3D printed robotic arm exoskeleton compared to the commercially available robotic arm exoskeleton. The 3D printed robotic arm skeleton was specifically built for the participants in the study, whereas the commercially available robotic arm exoskeleton was developed for one particular size. In addition, the 3D printed robotic arm exoskeleton is approximately 2 lbs in weight, compared to the 6 lbs weight of the commercially available robotic arm exoskeleton.

CHAPTER 4

FUTURE WORK

Relationship Between Mean Time Spent Exercising and Robotic Arm Exoskeleton Weight

As discussed in the results section, the results show that there might be a relationship between the mean time spent exercising on a robotic arm exoskeleton and the weight of the robotic arm exoskeleton. Future work will include developing a further relationship between mean time spent exercising and the weight of the robotic arm exoskeleton. Being able to quantify the relationship will allow for a more optimized robotic arm exoskeleton.

Scaling

Arm, wrist, and hand measurements do not necessarily linearly scale, but the scaling of the robotic arm exoskeleton is a nonlinear operation. The able-bodied participants who participated in the study, however, had fairly normal arm, wrist, and hand measurements, which allowed a linear scale factor to approximate the nonlinear scaling. In the future, it will be necessary to investigate nonlinear scaling to allow for a more optimized robotic arm exoskeleton, catered to a specific person, regardless of how different their arm, wrist, and hand measurements are.

Expansion of Application Spaces

Currently, this research pertains exclusively to the addition of the robotic arm exoskeleton gaming suite with regards to wrist rehabilitation exercises. In the future, it would be important to extend the application spaces of this research to other exercises in the arm/hand area. In particular, grip strength exercises appeal to experimentation, as hand function in general has been linked to being one of the most important factors in developing a higher perceived quality of life [11].

CHAPTER 5

CONCLUSION

Cerebral palsy and stroke are both debilitating neurological disorders that affect a person's perceived quality of life, almost always for the rest of their life. In the recent past, the field of robotic arm exoskeleton rehabilitation therapy has emerged, seeking to maintain a patient/survivor's perceived quality of life for as long as possible via encouragement. However, not only is rehabilitation typically not encouraging or entertaining, but robotic arm exoskeletons typically do not exist for various size groups and are generally bulky and heavy in nature.

This research explores the development of a robotic arm exoskeleton for use in in-home rehabilitation. The development is completed through SolidWorks and is fabricated using 3D printers, in order to develop the robotic arm exoskeleton inexpensively and without relatively much weight. The robotic arm exoskeleton was validated using an experiment to test the efficacy of the fabricated robotic arm exoskeleton versus the commercially available Hand Mentor. In this experiment, it was shown that the mean time spent exercising without taking breaks was significantly higher while using the fabricated robotic arm exoskeleton than without. Potential future work was discussed, including quantifying the relationship between the mean time spent exercising with the robotic arm exoskeleton and the weight of the robotic arm exoskeleton, introducing nonlinear scaling, and expanding the application space of this rehabilitation therapy.

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VITA

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